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CL XI NOZZLE F2 ABSORPTION EXPERIMENT.(U)

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CL XI Nozzle F_2 Absorption Experiment

Aerophysics Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

15 June 1977

Interim Report

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This technical report has been reviewed and is approved for publication.

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An F_2-absorption diagnostic technique was developed to determine F_2 densities in the flow of a 10.2-cm-long TRW CL XI nozzle. The device was transported to the site, set up, tested, and returned to TRW in two days. Hence, the diagnostic device was demonstrated to be readily transportable and to be operable in a combustion-driven, chemical-laser field environment. Cold- and hot-flow measurements up to 970 K plenum temperature, i.e., no F_2 dissociation, were in agreement; therefore, this measurement technique appears to be ——— over

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reliable. The use of C_2H_4 as a combustor fuel did not result in particulate absorption or scattering of sufficient magnitude to affect the measurement. The flow dissociation level for this nozzle was shown to be >0.8. The measurement sensitivity achieved in these tests was $\Delta I/I_o = 6 \times 10^{-4}$, which corresponds to an F_2 density of 6.76×10^{-6} mol/l (0.127 Torr F_2 at 300 K) for a 10.2-cm path length.

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PREFACE

The authors wish to express appreciation to Dr. C. Clendening of TRW for his invaluable assistance during the tests and data reduction and interpretation.

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I. INTRODUCTION

Absorption by the F_2 continuum at a 325-nm wavelength was used to determine the F_2-concentration (Ref. 1). A HeCd laser capable of being modulated was used to probe the flow. The difference in intensity between the laser beam transversing the region of absorption measurement and a reference beam was measured by means of two independent, silicon, photovoltaic detectors. The differential voltages were displayed on an oscilloscope. Several refinements to the basic differential measurement technique were essential to achieve sufficient sensitivity to obtain meaningful data for an operational laser (sensitivities of $\Delta I/I_o \leq 10^{-4}$ in laboratory tests and $\Delta I/I_o = 6 \times 10^{-4}$ in the CL XI nozzle field tests have been obtained). Figure 1 is a schematic of the technique, with essential refinements illustrated.

Internal laser modulation provided transient free chopping of the two beams. A sapphire prism was used to ensure complete polarization of the beam to eliminate polarization difference effects in reflectivity and transmissivity of optical parts in the light paths. The optical density wedge provided a null differential signal with no F_2 flow. The 325-nm wavelength optical filter was used to discriminate against hot-flow radiation. The test cell was darkened for testing, and the detectors were tuned for optimum gain by translation transverse to the beams. The low-pass filter of the 1A7A differential amplifier eliminated high-frequency noise above 100 Hz. Measurement beam in-operation (I_o) was read directly on the scope for the no F_2 condition. The reference beam was then made equal to I_o to within 1 part in 10^4 by means of the optical density wedge. The measured intensity difference (ΔI) resulting from F_2 abosrption was read directly on the scope at a high sensitivity for the F_2 addition in the absorption region as the difference between the modulated-on and modulated-off beam traces. The F_2 density for small concentration was determined directly from the equation

$$\rho_{F_2}(\text{mol/l}) = \frac{1}{8.70\ell(\text{cm})} \frac{\Delta I}{I_o}$$

where the absorption coefficient is obtained from Ref. 2, ℓ is the absorption path length (L in the Appendix), and ρ_{F_2} is the molecular fluorine molar density.

The important components of the absorption experiment, which are shown in Figure 1, include: a Liconix Model 301 M modulatable laser (325-nm wavelength), an Interstate Electronics Model P25 pulse generator, two EG & G Model UV 444B silicon photovoltaic detectors, a Tektronix Model 1A7A 10-μV sensitivity differential amplifier, a sapphire prism, three CaF_2 windows, and a 325-nm wavelength optical filter.

II. EXPERIMENT

Fluorine density measurements were made in the TRW CL XI nozzle flow along the 10.2 cm path. The tests were conducted on 5 and 6 August 1976 in the HEPTS facility at the TRW Capistrano test site. The basic experimental setup is shown in Figure 1. The absorption measurement beam was placed 1.65 and 6.73 cm downstream of the nozzle exit plane in the center of the jet. Cold-flow test runs were made with F_2 as the He diluent. Hot-flow test runs were made with F_2 with C_2H_4 or H_2 as the combustor fuels and He as the diluent. Helium was also fed into the cavity through the fuel nozzles to maintain proper nozzle operating temperatures during hot-flow runs; however, no cavity fuel was used in these tests. In addition, He was used as a window and cavity purge gas.

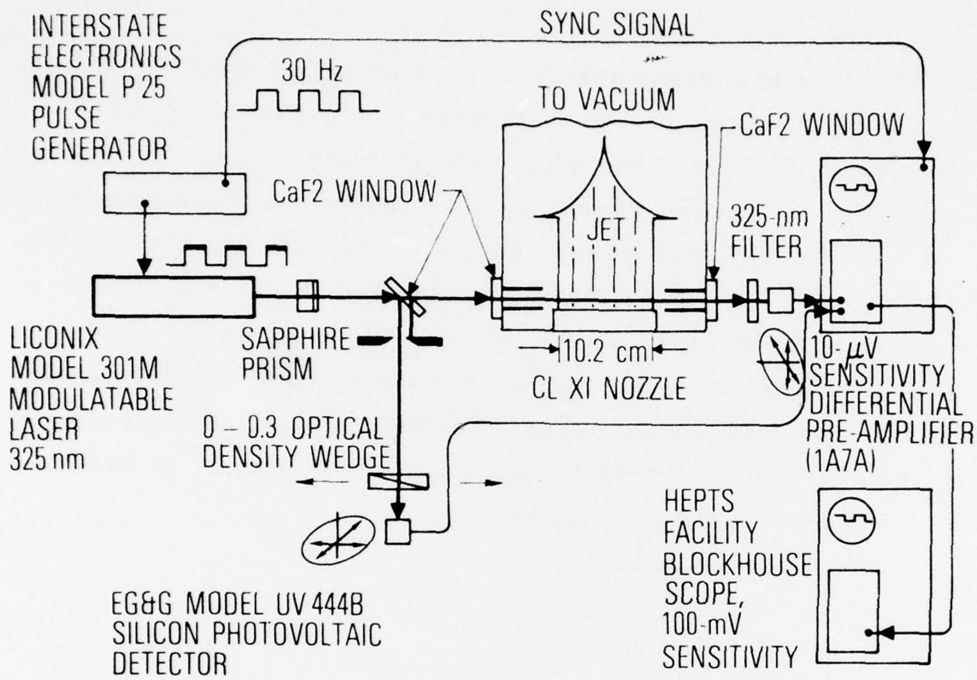

Figure 1. CL XI Nozzle F_2 Absorption Experiment

III. CALIBRATION

Absolute cold-flow calibrations were attempted to verify the techniques in the new test environment and to establish baseline measurements for the test series. The cold-flow absorption measurements near the nozzle (X = 1.65 cm) yielded low values of F_2 density. The values were low when compared to the F_2 densities calculated to be in the cavity flow, on the basis of an isentropic expansion of the known F_2 in He molar flow from the plenum of known pressure to the measured cavity pressure, i.e., 234 μmol/l measured relative to 387 μmol/l or a 40% discrepancy. This result was probably due to the disparity between the measured cavity pressure and the actual static pressure of the jet in proximity to the nozzle resulting from an overexpansion of the flow. Cold-flow measurements made at this point were the same with and without He flow-out of the cavity fuel nozzles, indicating that the measurement was being made well within the Prandtl Meyer zone and that little mixing had occurred between the two streams at this point. Cold-flow measurements made at the X = 6.73 cm station were in better agreement. The calculated F_2 density was 438 μmol/l, and the measured value was 339 μmol/l, an agreement within 23%, but still a rather large discrepancy. Similar measurements made at the Aerospace facility agreed within a few percent (Ref. 1). This discrepancy is thought to be to result, in large measure, from the sizable cavity-purge He flow (6 g/sec), which in mixing with the jet could account for the lower F_2 density measurements. However, effects of this ambient gas in the cavity on the measurement are difficult to assess quantitatively. The addition of 21 g/sec of He into the cavity jet through the fuel oxidizer nozzle, which was necessary during all hot runs, resulted in a cold-flow signal reduction of 23%. Because of the ambiguities introduced by these other cavity flows, the jet flow could not be used to verify the diagnostics precisely; they indicate only that the measurements are reasonable. The F_2 density measurement does reflect the flow condition. The near-nozzle measurement, for example, yields a cavity pressure and temperature of 1.67 Torr and 114 K for an isentropic nozzle expansion. The cold-flow measurements provide baseline information from which hot-flow dissociation levels can be calculated. The cold flow test conditions are as follows:

$m_{He_{combustor}} = 12.73\ g/sec^{-1}$

$M_{F_{2_{combustor}}} = 27.34\ g/sec^{-1}$

$P_{combustor} = 40.8$ psia

$T_{combustor} = 295°K$

$m_{He_{cavity\ purge}} = 6.0\ g/sec^{-1}$

$p_{cavity} = 4.5$ Torr

$L_{path\ length} = 10.2$ cm

I_o measured $= 7.5 \times 10^{-3}$ V

$X = 1.65$ cm, 6.73 cm

$\Delta I_{measured} = 156\ \mu V,\ 226\ \mu V$

$\rho_{F_{2\ calculated}} = 387\ \mu mol/l,\ 438\ \mu mol/l$

$\rho_{F_{2\ measured}} = 234\ \mu mol/l,\ 339\ \mu mol/l$

IV. RESULTS

Both H_2 and C_2H_4 were used as fuels in the combustor in these tests. The use of C_2H_4 as a combustor fuel did not result in particulate absorption or scattering of sufficient magnitude to negate the measurement technique, which was a matter of concern because of the extreme sensitivity of Raman scattering to unwanted scattering in the flow. Reliable measurements can be made with C_2H_4 as the combustor.

Measurements were made at two locations, x = 1.65 cm and 6.7 cm downstream of the nozzle exit plane. The typical test results for three combustor temperatures obtained at the x = 1.65 cm location are given in Table 1.

Table 1. Near-Nozzle Test Results

T_t, K	$\Delta I/I_o$	$\Delta I/I_o$ ($T^{-1/2}$ extrapolation)	Flow Dissociated (α) Level
295	2.1×10^{-2}		0
971	7.6×10^{-3}	8.7×10^{-3}	0.046
1998	$<6 \times 10^{-4}$	2.8×10^{-3}	>0.8

The combustor temperatures were calculated from the TRW MDRC computer program. The $\Delta I/I_o$ measurements were made directly with the F_2 diagnostics, and the $\Delta I/I_o$ ($T_t^{-1/2}$ extrapolation) values were calculated on the basis of the 295 K reading by means of a $T_t^{-1/2}$ scaling law. Both the F_2 consumed by the combustor and the MDRC Program computed dissociation were taken into account (see the Appendix for a discussion of the data reduction techniques). The scaled $\Delta I/I_o$ value at 971 K, i.e., 8.7×10^{-3}, is in good agreement with the measured value, 7.6×10^{-3}, indicating the reliability of the technique and data-handling method for hot flows. Further extrapolation to 1998 K for an assumed 100% recombination resulted in an absorption signal of 2.8×10^{-3}. However, no absorption difference signal was detected in several attempts. It was estimated conservatively that a difference signal of 6×10^{-4} would have been observed. It was concluded that these tests indicated a flow (α) for this high-temperature of >0.8. Test conditions and measurements for these tests are given in Table 2.

The measurements made at the $x = 6.7$ cm location were made with 21 g/sec He flowing into the cavity through the fuel nozzle array, which precluded absolute flow density calculations on the basis of isentropic expansion. A $T_t^{-1/2}$ correlation of the data points obtained over a range of temperatures from 964 to 1633 K was made with the 964 K value. The downstream-of-nozzles test conditions and measurements data are given in Table 3. The relative absorption measurements are shown in Figure 2 versus the combustor temperature. Theoretical curves representing 100% recombination and no recombination were also plotted for comparison with the experimental values. The theoretical curves were scaled to fit 964 K and multiplied by $T_t^{-1/2}$ for the higher temperatures. The basic agreement of the experimental points and the no recombination curve is good. The average recombination level indicated over the entire range of temperatures appears to be of order 10 to 20%; i.e., $\alpha \simeq 0.8$ to 0.9.

Table 2. Near-Nozzle Test Conditions and Measurements[a]

Test No.	$\dot{m}_{F_2}$, g/sec	$\dot{m}_{H_2}$, g/sec	$\dot{m}_{He}$, g/sec	P_t, psia	P_c, Torr	T_t, K	α	$\dot{n}_{F_2}$ (undissociated), mol/sec	$\frac{\Delta I}{I_o}$	ρ_{F_2}, mol/l
HB5-4161	27.34	0	12.73	40.5	3.7	295	0	0.719	2.1×10^{-3}	2.4×10^{-5}
HB5-4164	27.34	0.3	12.73	71.6	5.6	971	0.0458	0.544	7.6×10^{-3}	8.6×10^{-5}
HB5-4160	27.34	2.2[b]	12.7	107	4.4	1998	0.9918	2.04×10^{-3}	$<6 \times 10^{-4}$	$<6.8 \times 10^{-6}$

[a] $x = 1.65$ cm; $\dot{m}_F$, $\dot{m}_{H_2}$, $\dot{m}_{He}$ ($\dot{m}_{C_2H_4}$), P_t, and P_c are measured quantities. T_t, α, and $\dot{n}_{F2}$ (undissociated) are calculated by means of the MDRC Program. $\Delta I/I_o$ is measured by the F_2 diagnostic, and ρ_{F_2} is calculated from $\Delta I/I_o$.

[b] $\dot{m}C_2H_4$, g/sec, for this value only.

Table 3. Downstream-of-Nozzle Test Conditions and Measurements

Test No.	$\dot{m}_{F_2}$, g/sec	$\dot{m}_{H_2}$, g/sec	$\dot{m}_{He}$, g/sec	P_t, psia	P_c, Torr	T_t, K	α	$\dot{n}_{F_2}$ (undissociated), mol/sec	$\frac{\Delta I}{I_o}$	ρ_{F_2}, mol/l
HB5-4165	27.34	0	12.73	40.8	4.5	295	0	0.719	2.1×10^{-2}	2.37×10^{-4}
HB5-4170	27.34	0.30	12.73	72.4	6.0	964	0.0421	0.546	7.20×10^{-3}	8.11×10^{-5}
HB5-4169	27.34	0.45	12.73	81.5	6.0	1140	0.1989	0.397	5.33×10^{-3}	6.01×10^{-5}
HB5-4168	27.34	0.60	12.73	88.3	5.5	1273	0.4466	0.233	3.13×10^{-3}	3.53×10^{-5}
HB5-4171	27.34	0.75	12.73	96.0	5.9	1429	0.7617	0.083	1.16×10^{-3}	1.31×10^{-5}
HB5-4172	27.34	0.90	12.73	104.7	5.7	1633	0.9484	0.014	2.67×10^{-6}	3.01×10^{-6}

[a] x = 6.7 cm; $\dot{m}_{F_2}$, $\dot{m}_{H_2}$, $\dot{m}_{He}$, P_t, and P_c are measured quantities. T_t, α, and $\dot{n}_{F_2}$ (undissociated) are calculated by means of the MDRC Program. $\Delta I/I_o$ is measured by the F_2 diagnostic, and ρ_{F_2} is calculated from $\Delta I/I_o$.

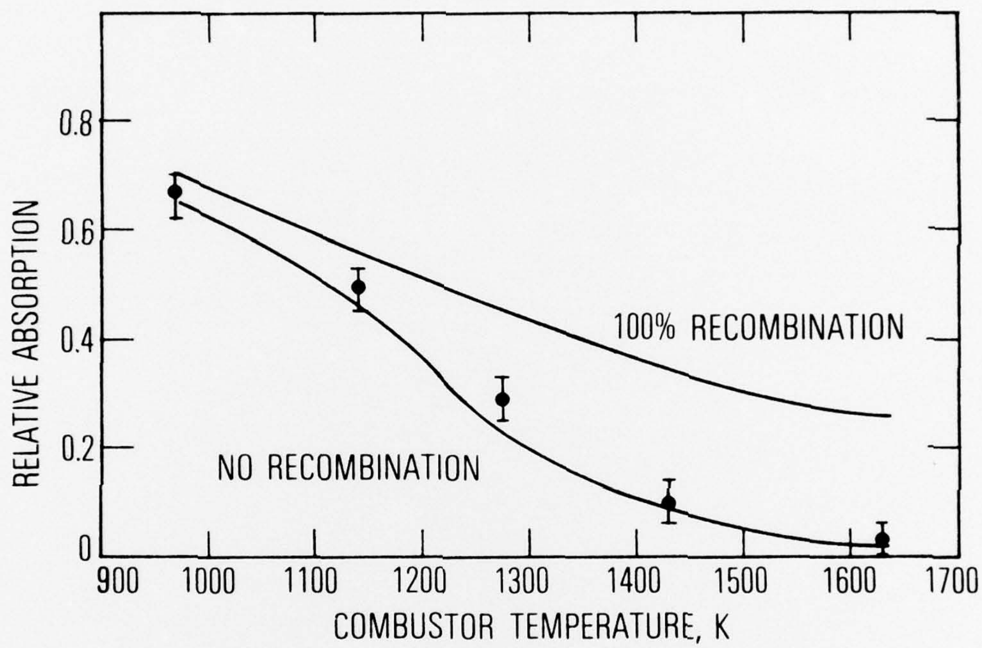

Figure 2. F_2 Absorption 6.7 cm Downstream of Nozzle Exit

V. DISCUSSION

Several difficulties were experienced in the tests, some of which can be eliminated or minimized in future testing. Recirculation of F_2 in the measurement region outside the jet occurred before window-purge ducts leading to the edges of the jet were installed. The measured absorption was reduced over one-half upon installation of the ducts. Window coating was necessary and resulted in a large reduction in the measurement beam signal (8 mV to 6 mV) in early tests. Sooting occurred after each purge gas (He) was turned on. The sooting apparently decreased as the lines cleared but was finally eliminated after the window ducts were added and the He purge gas in the window was increased from 3 to 6 g/sec. Individual small-scale ducts (to reduce cavity flow) for each window are recommended.

Problems with near nozzle measurements stemmed from the lack of precise knowledge of flow-static pressure or temperature. The diagnostics provide F_2-density information, and relative measurements can be made of this density under flow rate or plenum temperature on pressure variation. However, the representation of F_2 concentration in such terms as pressure or degree dissociation requires either the measurement of another flow parameter, such as jet static pressure, or a nozzle flow calculation. In an equilibrated jet, the downstream F_2 measurement permits the readily accessible cavity static pressure measurement to be used to aid in analysis. The presence of large purge flows in the cavity region, however, complicates the analysis and reduces the utility of this simple flow measurement to the F_2 jet analysis. With the use of individual small-bore (< 1-in-diam), long-window ducts with small-window H_2 purge flows and with no cavity purge gas introduced, this measurement problem might be solved.

The two principal difficulties associated with the measurement device itself, not the flow field, are electrical noise pickup (principally 60 Hz) and the long-term drift of the differential signal. A significant reduction in electrical noise pickup was made at the site by replacing coaxial leads connecting the detectors to the scope differential amplifier input terminals with twisted-pair cabling. Further reduction should be possible with the use of shielded twisted cables with greater electrical noise attenuation characteristics. Increased discrimination against electrical noise is possible by means of the measurement of the difference signal from the differential amplifier output on a lock-in amplifier. However, for the phase-sensitive amplifier to be used efficiently, long-term drift must be taken into account. The long-term drift was thought to be the result, principally, of dissimilar thermal changes in the detectors in the open-test environment. An increase in thermal inertia by means of mass addition to the detector holders should improve this condition.

The most promising way to increase the signal-to-noise ratio involves the use of a higher-powered laser source. The Liconix Model 301M laser used in these tests provided a 1-MW beam. Newer models, e.g., Liconix Model 405 UV, provide an order of magnitude or greater output power at the 325-nm wavelength.

VI. CONCLUSIONS

The Aerospace F_2-absorption diagnostic technique was applied to the measurement of F_2 densities in the flow of the TRW CL XI nozzle. The technique was shown to be viable in a combustion-driven, chemical-laser environment. Cold- and hot-flow measurements under essentially no F_2 dissociation, i.e., combustor-plenum temperatures of 295 K ($\alpha = 0$) and 971 K ($\alpha = 0.046$), were consistent. Hence, the measurement technique appears to be reliable. Extension of the tests to higher temperature regions ($T_{max} = 1998$ K) indicated consistently low recombination levels, i.e., $\alpha > 0.8$, for this nozzle. Particulates were not a problem, even when C_2H_4 was used as the combustor fuel. Whereas the system performed satisfactorily, in this test, series sensitivity was limited to $\Delta I/I_o = 6 \times 10^{-4}$, which corresponds to an F_2 density of 6.76×10^{-6} mol/l (0.127 Torr F_2 at 300 K) over a 10.2-cm path. Sensitivity and data-acquisition reliability may be improved by increasing the HeCd-laser-beam power, increasing the thermal inertia of the detectors, including a phase-sensitive amplifier readout in the system, and by decreasing electrical noise pickup.

APPENDIX A

DATA ANALYSIS

The basic equation used in the analysis of the F_2-absorption experiment data is the classical absorption law

$$\frac{I}{I_o} = e^{-8.70\, \rho_{F_2}(\mathrm{mol/l})\, L\,(\mathrm{cm})} \qquad \text{(A-1)}$$

where the absorption coefficient is given for F_2 at 325 nm wavelength (Ref. 2).

The absorption measurement involves the determination of I_o and ΔI. Equation A-1 can be rearranged, to directly reflect the relationship between ρ_{F_2} and the measured quantities, to the form

$$\frac{\Delta I}{I_o} = 1 - e^{-8.70\, \rho_{F_2} L} \qquad \text{(A-2)}$$

For small values of the argument of the exponential (the case here), this expression can be further simplified and rearranged to the form

$$\rho_{F_2} \simeq \left(\frac{1}{8.70L}\right)\frac{\Delta I}{I_o} \qquad \text{(A-3)}$$

Hence, the F_2 molar density is determined directly in the experiments from geometry, i.e., nozzle absorption path length (10.2 cm) and the measure beam values.

A basic difficulty in data application is immediately encountered upon attempting to relate the measured F_2 densities in the flow to the dissociation level, i.e., another gas flow parameter in the jet must be measured or inferred in order to accomplish this. Cavity pressure is a readily measured quantity and can be equated to downstream-jet static pressure in some instances to fill this need and has been successfully done in previous experiments at Aerospace. Unfortunately, the large addition of purge gases to the cavity region in the present tests precluded unambiguous use of the cavity pressure measurement in the data analysis, which otherwise might be accomplished as follows.

Cavity F_2 molar densities in the jet are calculated for known plenum pressure, temperature, and molar flow rates and cavity pressure, with isentropic nozzle expansion assumed and with the aid of the equations

$$\rho_{F_2} = \frac{\dot{n}_{F_2}}{\dot{n}_{total}} \rho_c \tag{A-4}$$

$$\rho_c = \rho_t \left[\frac{p_c}{p_t}\right]^{1/\gamma} \tag{A-5}$$

and

$$\rho_t = \frac{p_t}{RT_t} \tag{A-6}$$

where ρ, p, and T are the density, pressure, and temperature, respectively, subscript t refers to plenum (total) conditions, subscript c refers to cavity conditions, R is the gas constant, γ is c_p/c_v, and $\dot{n}$ is the molar flow rate. This calculation was performed only for the cold-flow calibration runs for comparison with the measured F_2 densities since the p_c measurement was compromised in these tests as explained in Section III of this report. γ was calculated to be 1.954 for the cold-flow calibration conditions.

The method used to relate the measured F_2 density to dissociation level in these tests involved establishing the combustor plenum temperature dependence of ρ_{F_2}. This was accomplished by the use of equations

$$\rho_c = \frac{\dot{m}}{AV} \tag{A-7}$$

and

$$V = M \sqrt{\gamma R T_t} \tag{A-8}$$

and Eq. (A-4), from which was obtained the functional dependence

$$\rho_{F_2} \propto \frac{1}{\sqrt{T_t}} \tag{A-9}$$

where $\dot{m}$ is the total jet mass flow, V is the jet velocity at the location, A is the jet cross-sectional flow area, and M is the flow Mach number. The combustor gas composition, temperature, and pressure were varied for the various runs by means of variable-combustor fuel injection, which resulted in only a small change in the quantities M, R, and γ as a result of the large diluent ratios employed. These parameters were disregarded in the analysis. The determination of F_2-dissociation level was made by measuring ρ_{F_2} for a cold flow (T_t = 295 K, α = 0) and hot flows and applying the $T^{-1/2}$ density scaling law to the cold-flow measurement. Comparison of this value with the hot-flow density measurement, which had been compensated for lower initial F_2 due to combustion and dissociation, yielded the recombination fraction. The combustor temperatures, gas compositions, and dissociation levels were directly from TRW Program MDRC. The combustor temperatures were calculated by means of a heat balance, which included the measured combustor heat losses but excluded nozzle heat losses.

REFERENCES

1. D. J. Spencer, Sensitive F_2 Absorption Diagnostic, TR-0077(2610)-3, The Aerospace Corporation (to be published).

2. R. K. Steunenberg and R. C. Vogel, "The Absorption Spectrum of Fluorine," J. Amer. Chem. Soc., 78, 901 (1956).

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